# NASA

# Capability Road Map (CRM) 12

# Science Instruments and Sensors

## Capability Cost Estimate

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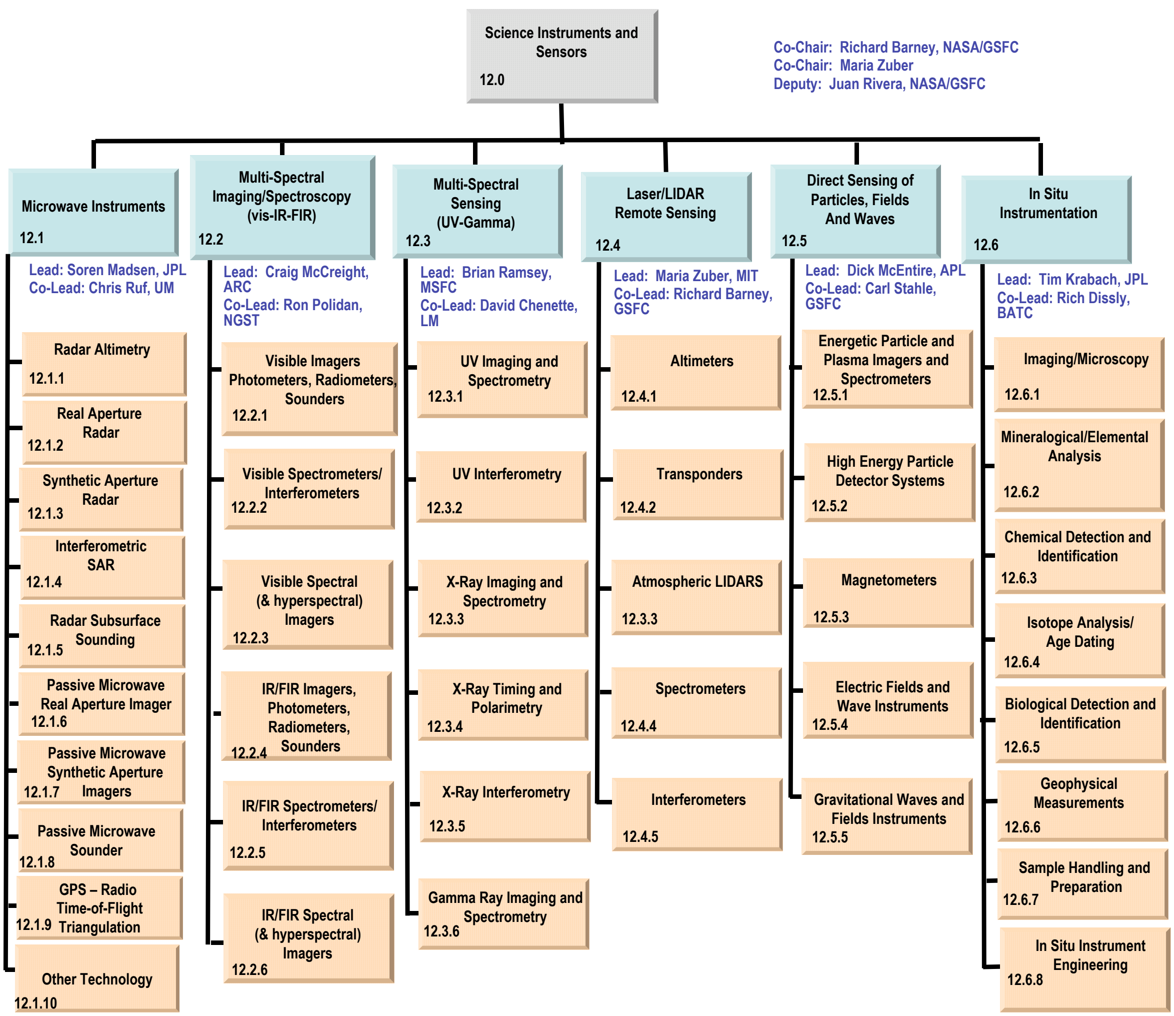
# 1 Science Instruments and Sensors Overview

The science instruments and sensor capability breakdown structure, shown in the Figure below, represents an attempt to group similar technologies which, for electromagnetic sensors, also maps closely to wavelength ranges. This approach produced a total of six capabilities; each one generally covers a very wide range of wavelengths and technologies, all supporting and linked to diverse science and exploration strategic objectives. The capability breakdown structure organization and numbering scheme was used throughout this capability costing exercise.



## Table: Capability Cost Estimates

| Capability Title | Sub-Capability | Major Milestone(s) | ROM Five-Year Cost (FY06 – 10) | ROM Run-out Cost | Notes (Mission Drivers) |
|---|---|---|---|---|---|
| 12.1 Microwave Instruments and Sensors | Integrated radar T/R modules | Efficiencies approaching 60% with single chip implementation | 3-10 | 10-30 | L-Band LEO & MEO Insert, Ocean Structure and Circulation, InSAR Land Topomapper |
| 12.1 Microwave Instruments and Sensors | Integrated radiometer receivers | 1000 elements @ 110GHz; Quantum limited @3THz with individual elements | 10-30 | 30-60 | Einstein Inflation Probe, Global Tropospheric Aerosols, Single Aperture Far Infrared Observatory |
| 12.2 Multi-Spectral Imaging / Spectroscopy (Vis-IR-FIR) | Visible, Near and Far-IR Detector Arrays and Readouts | Vis: 5E8 BLIP CCDs with ASIC @4 electrons<br>Far-IR: 1E4 BLIP with low NEP | 60-100 | 100-300 | TPF-C, Joint Dark Energy Mission, Single Aperture Far Infrared Observatory |
| 12.1 Microwave Instruments and Sensors<br><br>12.2 Multi-Spectral Imaging / Spectroscopy (Vis-IR-FIR)<br><br>12.3 Multi-Spectral Sensing (UV-Gamma) | Active Cooling Systems | 7 year lifetime 4-6K Cryo Coolers for large telescopes and structures<br><br>7 year lifetime 10mK Cryo Coolers for Far-IR and high energy detectors/readouts | 30-60 | 60-100 | Einstein Inflation Probe, Single Aperture Far Infrared Observatory, Neptune Orbiter with Probes, Joint Dark Energy Mission, Constellation-X, |
| 12.4 Laser / LIDAR Remote Sensing<br><br>12.5 Direct Sensing of Fields, Particles, and Waves | Lasers: Long Lifetime High Power, High Frequency Stability | 5 year lifetime 3W lasers with 2Joules/pulse<br><br>7 year lifetime 300W lasers with low noise for Interferometry applications | 60-100 | 100-300 | Lunar Recon Orbiter, Stratosphere Composition, Laser Interferometer Space Antenna, Global Troposhere Winds, Advanced Land Cover Change |
| 12.1 Microwave Instruments and Sensors<br><br>12.3 Multi-Spectral Sensing (UV-Gamma)<br><br>12.5 Direct Sensing of Fields, Particles, and Waves | Low power, radiation hard electronics | High efficiency DC-DC converters<br><br>Radiation hardened A/D converters | 3-10 | 10-30 | L-Band MEO InSAR, Sea Ice Thickness, Global Tropospheric Aerosols, GEO Global Precipitation Doppler Radar/Passive Imager, |

| Capability Title | Sub-Capability | Major Milestone(s) | ROM Five-Year Cost (FY06 – 10) | ROM Run-out Cost | Notes (Mission Drivers) |
|---|---|---|---|---|---|
| 12.5 Direct Sensing of Fields, Particles, and Waves | Particle detectors with integrated electronics | Ion implanted SSDs 15 micron to 5 mm thinkness<br><br>Large arrays with low power, low noise, rad hard electronics | 3-10 | 10-30 | Europa Geophysical Orbiter, Inner Heliosphere Sentinels (IHS), Solar Probe, Mag Con, Telemachus, Interstellar Probe (ISP), Heliospheric Imager and Galactic Observer (HIGO) |
| 12.6 In Situ Instrumentation | Comprehensive biomarker and organic assessment | Lab based Multiple assay techniques need ppb sensitivity and miniaturization to flight scales | 60-100 | 100-300 | Mars Deep Drill, Mars Foundation Laboratory, Titan Explorer, Europa Pathfinder Lander, Europa Astrobiology Lander |
| 12.6 In Situ Instrumentation | Sample handling with minimal sample alteration or contamination | 40K demo of cryo mechanism<br><br>mm-scale sampling of sedimentary layers<br><br>No heating of samples required above -20C | 60-100 | 100-300 | Lunar Polar Explorer, Comet Surface Sample Return, Comet Cryo Sample Return, Mars Deep Drill, Europa Pathfinder Lander, Mercury Sample Return, Comet Surface Sample Return, Venus In Situ Explorer, Europa Pathfinder Lander |

## 12.1 Microwave Instruments and Sensors

Microwave Instruments and Sensors include active microwave instruments (radar), passive radiometers, microwave navigation sensors (GPS) and crosscutting technologies such as cryogenic coolers and radiation hard electronics. The frequency range covered ranges from 30kHz to 3THz. Key components include antennas, receivers, transmitters and signal and data processing electronics. The most important enabling capabilities include integrated radar transmit and receive modules and integrated radiometer receivers. Both are shown in this Science Instrument and Sensors Capability Cost Estimate.

The basis of estimate are the NASA investments from the Earth Science Technology Office (ESTO) such as the Advanced Component Technology Program and Earth Incubator Program, Advanced Technology Microwave Sounder (ATMS) technology development, and the JPL research and development program.

### 12.1.1 Integrated Radar Transmit and Receive Modules

Integrated Radar T/R Modules is an enabling capability for several potential InSAR missions including L-Band LEO & MEO InSAR, Ocean Structure and Circulation, and InSAR Land Topomapper.

The T/R Module is a key component which provides gain, power and phase control to both the transmit and receive signal paths of an active Space Based Radar System. One major capability challenge involves the efficiency of the great number of T/R modules required by future very large antennas. Significant trade options exist in the choice of materials, packaging, and design implementation architectures. Additionally, technology issues such as being able to generate significant power up at W-Band using flexible membrane technology require focused technology resources to solve.

Our technology roadmaps call for high (60%) efficiency arrays at L-Band in 2006-2010. Missions after 2010 will require T/R modules capable of transmitting 1 watt at RF. Lastly, integrated L- and Ka-Band arrays required by missions beyond 2020 need single arrays that contain T/R modules at multiple frequencies. A major challenge will be integrating multiple modules onto a single membrane structure.

### 12.1.2 Integrated Radiometer Receivers

Integrated Radiometer Receivers is an enabling capability for several potential Passive Microwave missions including Einstein Inflation Probe, Global Tropospheric Aerosols, and Single Aperture Far Infrared Observatory. The digitizing receiver is required by passive radiometers and basically amplifies a thermal emission signal, down-converts it to baseband, and digitizes it. Digitizing receivers are the core elements of passive synthetically thinned aperture arrays such as would be used by the Einstein Inflation Probe.

Of particular interest is the development of high spatial resolution imagers of broadband thermal, gaseous absorption line and solar radio emission with a thinned aperture using interferometric software beam forming. Many applications, including imaging of solar radio bursts, ocean, ice, land and subsurface features and atmospheric water content, and sounding of atmospheric gasses require integrated receivers.

Currently, the technologies such as first-generation hybrid MMIC-based receivers are being developed under the NASA Instrument Incubator program with flight heritage under projects such as JASON-1. Technology challenges include developing modules that will be needed by STAR receivers at 19 and 37 GHz. Additionally, receivers are needed that operate at multiple GHz frequencies with an MHz bandwidth, include back end digitizer sampling with low power requirements.

Future development efforts should focus on next generation integrated receiver modules that have features such as:

- imbedded band definition stages to eliminate the need for custom tuning
- improvements in the repeatability, phase and amplitude matching between units
- reduction of the DC power requirement to 1⁄2 watt/each;
- incorporation of custom low power STAR- optimized analog-to-digital converter
- reduction in the recurring costs of multiple units

## 12.2 Multi-Spectral Imaging/Spectroscopy (VIS-IR-FIR)

Multi-Spectral Imaging/Spectroscopy (VIS-IR-FIR) includes sub-systems and components covering wavelengths from 0.4 to 1000 µm. The key sub-capabilities are detector arrays, instrument-level optics and filters, mechanisms, (internal) calibration sources, electronics, as well as ancillary technologies, *e.g.* cryogenic coolers, and data processing systems. The most important enabling capabilities include visible, near and far-IR detector arrays and readouts and active cooling systems. Both are shown in this Science Instrument and Sensors Capability Cost Estimate.

### 12.2.1 Visible, Near and Far-IR Detector Arrays and Readouts

Visible, Near and Far-IR Detectors and Readouts are enabling capabilities for several astrophysics missions including TPF-C, Joint Dark Energy Mission, and the Single Aperture Far Infrared Observatory.

Significant detector technology breakthroughs will be required over the next 5 years to enable the production of multi-wavelength large format arrays. The table below summarizes current and needed technologies in the field of large format detector arrays.

| **Sub Capability** | **Figures of Merit** | **Current Technology** | **Needed Technology** |
|---|---|---|---|
| Visible Detector Arrays | Pixel Count, Uniformity<br>Quantum Efficiency<br>Noise<br>Crosstalk | ≤1 k x 2 k format<br>Radiation degradation<br>Transition (CCD <-> CMOS)<br>Few, changeable foundaries | >2 k x 2 k format; mosaics<br>Radiation tolerance<br>Stable fabrication infrastructure |
| IR Detector Arrays | Pixel Count<br>Noise<br>Power Dissipation<br>Frame Time, and ability to sync to scene | ~1E4 pxls for some applications<br>~1E6 pxls for astrophysics, limited mosaics<br>Low-T's required<br>Irregular effects | Large formats for all applications; mosaics<br>Higher T arrays proven<br>Wider spectral response<br>Linear, fast response<br>High-throughput fab & testing |
| Far-IR Detector Arrays | Pixel Count, Uniformity<br>Quantum Efficiency<br>Noise<br>Crosstalk | Parallel investigations of best detection approaches<br>Early development of readout / mux approaches<br>Limited system demonstrations | Mature 1E4 pxl background-limited arrays<br>Demonstration of polarization, & 0.1-0.3 K cryogenics<br>High-T FIR broadband detectors<br>Stable fab & testing |

This critical capability also includes low-noise first-stage electronics to efficiently process / deliver signals through the digitization stage. These readout electronics must be compatible with the operating environment (radiation, T, etc.) and usually include drive & readout functions, on-FPA A/D conversion, and ASIC-type integrated implementations.

Basis of estimate are the Science Mission Directorate detector development technology funding, other government agency's detector technology development programs, multi-phase SBIR proposals, and science community input.

12.2.2Active Cooling Systems

Active Cooling Systems is an enabling capability for many exploration driven missions such as Single Aperture Far Infrared Observatory, Neptune Orbiter with Probes, and Joint Dark Energy Mission. Active cooling technologies such as stored cryogens, cryocoolers, radiative coolers, adiabatic demagnetization refrigerators, dilution refrigerators and sorption coolers are required to meet science and exploration objectives.

Current state of the art in the 10-60K temperature range includes stored cryogens (solid hydrogen and neon), multi stage cryocoolers, specialized use of high temperature superconductors, and a recent advancement in the use of hydrogen sorption coolers. Future imagers and spectrometers will require more efficient and longer life cooling systems. Miniaturized cryocoolers will need to be developed for lunar and interplanetary missions. Development of efficient multistage coolers and ADR/cryocooler hybrid systems will enable large focal planes of the future to operate in a thermally stable environment. The table below outlines the active cooling current and needed technologies.

| Sub Capability | Figures of Merit | Current Technology | Needed Technology |
|---|---|---|---|
| ≥6 K Cryocoolers for Space | Ultimate temperature<br>Thermodynamic Efficiency<br>Lifetime<br>Vibration | Limited flight experience<br>Sig. reluctance to adopt in projects<br>Life tests in lab-prel. but encouraging | Flight experience<br>No reluctance to adopt in projects<br>Long-life proven in lab (unattended) |
| Sub-kelvin coolers | Ultimate temperature<br>Thermodynamic Efficiency<br>Lifetime | Few systems developed & qual'd for flight<br>Alternate systems under investigation | Mature, high-efficiency systems for zero-g<br>Proven when staged to adv. 6 K coolers |

The basis of estimate are the NASA Advanced Cryocooler Technology Development Program, Science Mission Directorate technology funding, Spitzer and JWST mission technology development funding and internal research funding from NASA centers.

## 12.3 Multi-Spectral Sensing (UV-Gamma)

Multi-Spectral Sensing (UV-Gamma) includes sub-systems and components for remote imaging and spectrometry for the UV to Gamma ray wavelength range, $\lambda < 0.4\ \mu m$ (energies larger than 3 eV). The key technologies are detector arrays and associated electronics plus ancillary equipment such as cryogenic coolers. . The most important enabling capabilities include low power radiation hardened electronics and active cooling systems. Both are shown in this Science Instrument and Sensors Capability Cost Estimate.

12.3.1 Low Power Radiation Hardened Electronics

Low Power Radiation Hardened Electronics is an enabling capability for many exploration driven missions. Evolutionary advances in radiation hardened electronics technology are needed to provide aerospace system designers a strategically hardened family of products to reduce risks in space and ensure mission success. The driving requirements for space flight microcircuit technology are low power, low weight, radiation hardness, and high reliability at a reasonable cost for very limited production orders. For example, recent advances in flight quality CMOS Programmable Logic Devices have become available at reasonable power levels and cost. However, for analog circuits and very low power digital circuits, discrete elements are still in widespread use.

The high cost of maintaining dedicated foundries to create space electronics has motivated an exploration of alternatives for next-generation space systems. One emerging technology, radiation hardness by design, has quickly evolved from a laboratory to a strategy that may well redefine the way electronic components are procured for space systems. CAD tools that can model these radiation effects and cell libraries that use a range of techniques have been developed at a number of government agencies, universities, and private companies during the past several years, culminating in the commercial production of low power radiation hardened memories, microprocessors, and application-specific integrated circuits that are being specified in NASA missions.

Basis of estimate are the Science Mission Directorate technology development funding, other government agency's space flight electronics technology development programs, multi-phase SBIR/STTR proposals, science community input and industry working groups.

<u>12.3.2 Active Cooling Systems</u>

Active Cooling systems are summarized under 12.2.2

**12.4 Laser/LIDAR Remote Sensing**

Laser/LIDAR Remote Sensing encompasses sub-systems and components for surface elevation and atmospheric layer height measurements, transponder and interferometer operation for precise distance measurements, scattering for aerosol and cloud properties and composition, and Doppler velocity determination for wind measurement. Wavelengths range from 0.3 to 2 µm. The key technologies include lasers (high power, multi-beam and –wavelength, pulsed and continuous wave), detectors, receivers, and scanning mechanisms. The most important enabling capabilities include <u>long lifetime lasers</u> and <u>high power frequency stabilized lasers</u>. Both are shown in this Science Instrument and Sensors Capability Cost Estimate.

<u>12.4.1 Long Lifetime Lasers</u>

Laser lifetime is an enabling capability for many exploration driven missions such as the Lunar Recon Orbiter, Stratosphere Composition, Global Troposhere Winds, Advanced Land Cover Change.

Laser lifetime, particularly in Nd:YAG lasers has been a limiting factor in current NASA LIDAR and laser altimetry missions. Achieving improved performance, extended reliability, and lower cost of ownership for these solid-state lasers often translates into developing diode lasers with higher output powers and longer lifetimes. Investment in NASA's Laser Risk Reduction Program has uncovered new information in materials contamination, optical damage, and derating scenarios have significantly improved the performance of current NASA laser space assets. Continued investment will ensure the flight qualification and significant space environment lifetime testing of solid state lasers over the next 2-3 years.

Additionally, new technologies such as fiber lasers hold great promise as long lifetime space lasers for a wide range of applications because they are truly solid-state with a minimum of exposed optical interfaces, have very high efficiency, and are capable of exceptional beam quality. NASA as well as DOD is currently developing this new laser technology.

The bases of estimate are the NASA Laser Risk Reduction Program, SBIR investments, discussion with NASA centers, and industry collaborations. Additionally, Laser and LIDAR missions such as ICESat, Mars Laser Altimeter and Mercury Laser Altimeter have invested significantly in improving laser lifetime.

12.4.2 High Power Frequency Stabilized Lasers

High Power Frequency Stabilized Lasers is an enabling capability for many exploration driven missions such as the Laser Interferometer Space Antenna (LISA), Global Troposhere Winds, and the Big Bang Observer. Stable high power lasers currently operate at about 30mW with frequency stability in the range of 1 part in $10^{13}$ in the lab. Future high power lasers will need to operate at 3-300Watts for 5 years with stability numbers reaching $10^{14}$ in space with minimal noise.

The bases of estimate are the NASA Laser Risk Reduction Program, SBIR investments, discussion with NASA centers, and industry collaborations, and technology investments from missions such as LISA.

## 12.5 Direct Sensing of Particles, Fields and Waves

Direct Sensing of Particles, Fields and Waves includes capabilities for in situ and remote sensing of particles (ions, electrons, neutral atoms, neutrons, cosmic rays); DC electric and magnetic fields, plasma waves, and gravity fields and waves. The sub-capability includes energetic particle and plasma imagers and spectrometers, high-energy particle detectors, magnetometers, electric fields and waves sensors, and gravitational waves and fields instruments. The most important enabling capabilities include Particle Detectors with Integrated Electronics and high power frequency stabilized lasers. Both are shown in this Science Instrument and Sensors Capability Cost Estimate.

12.5.1 Particle Detectors with Integrated Electronics

Particle Detectors with Integrated Electronics is an enabling capability for many exploration driven missions such as the Europa Geophysical Orbiter, Inner Heliosphere Sentinels (IHS), Solar Probe, Mag Con, Telemachus, Interstellar Probe (ISP), Heliospheric Imager and Galactic Observer (HIGO).

Current state-of-the-art solid state detectors (SSD) energy thresholds are greater than 10KeV with limited array size, high power, and electronics that are inefficiently integrated to the array. Future missions such as the Interstellar Probe will require Ion large arrays of implanted detectors with low noise, radiation hardened electronics, UV suppression blocking technology, and stable charge conversion coatings. New advances in MEMS, Nano, and materials technologies will be needed to meet the requirements of the table below.

| **Sub Capability** | **Figures of Merit** | **Current Technology** | **Needed Technology** |
|---|---|---|---|
| Particle Detectors (plasmas, energetic electrons, ions, neutrals) | Energy/species/charge coverage and resolution, Solid angle coverage and resolution, Dynamic range | Electrostatic analyzers; Time-of-Flight (TOF) and Solid State Detector (SSD) telescopes | Compact sensors with better energy/angle coverage; Low threshold array detectors; UV blind gratings; Conversion surfaces; Highly integrated signal processing |

Basis of estimate are the Science Mission Directorate technology development funding, other government agency's space flight particle detector technology development programs, multi-phase SBIR/STTR proposals, science community input and industry working groups.

12.5.2 High Power Frequency Stabilized Lasers

High Power Frequency Stabilized Lasers are summarized under 12.4.2

## 12.6 In Situ Instrumentation

In Situ Instrumentation required by future NASA missions ranges from close range electromagnetic sensors to the full gamut of analytical chemistry and modern molecular biology techniques. Techniques for acquiring, handling, processing, and storing samples are required. In addition to miniaturizing traditional laboratory size equipment, the instruments must be capable of operating in extreme environmental conditions of temperature, radiation, pressure, and corrosiveness, potentially with stringent planetary protection requirements. The most important enabling capabilities include comprehensive biomarker and organic assessment and sample handling with minimal sample alteration or contamination. Both are shown in this Science Instrument and Sensors Capability Cost Estimate.

12.6.1 Comprehensive biomarker and organic assessment

Comprehensive Biomarker and Organic Assessment is an enabling capability for many exploration driven missions such as Mars Deep Drill, Mars Foundation Laboratory, Titan Explorer, Europa Pathfinder Lander, and Europa Astrobiology Lander.

Biomarkers in geological samples are products derived from biochemical precursors by reductive and oxidative processes. They are the keys to unlocking the most compelling science questions involving life on other planets. Current technologies needed to assess geological samples from throughout the solar system will need a revolutionary advancement to meet future needs. Geological labs will need to be shrunk in scale to fit on a single chip and measure parts-per-billion (or trillion). The table below summarizes the state of technology and assessment hurdles.

| **Sub Capability** | **Figures of Merit** | **Current Technology** | **Needed Technology** |
|---|---|---|---|
| Biomarker Detection and Characterization | • Sensitivity<br>• Selectivity<br>• Contamination ID and quantification | • Characterization of viable organisms that can be cultured<br>• Terrestrial contamination exceeds detection limits | • Quantitative assessment of all organic material<br>• Technology to ensure isolation from terrestrial contamination |

Future missions specify ppb and ppt sensitivities for lab-on-a-chip organic assessment for a couple of reasons: a) ppb is achievable now for several flight instrument concepts, although not necessarily in this miniaturized form, b) since sub ppt levels are achievable in terrestrial labs, scientists will demand similar sensitivities for organics on Mars by the time AFL launches. Scientists believe that we need high sensitivity to detect and interpret the evolution/digenesis of carbon on Mars and other planetary targets.

Basis of estimate are NASA technology programs for planetary science including the Planetary Instrument Definition and Development Program (PIDDP) and Mars Instrument Definition and Development Program (MIDDP), NASA's planetary missions, science community input and industry working groups.

<u>Sample Handling with minimal sample alteration or contamination</u>
Sampling Handling with Minimal Sample Alteration or Contamination is an enabling capability for many exploration driven missions such as Lunar Polar Explorer, Comet Surface Sample Return, Comet Cryo Sample Return, Mars Deep Drill, Europa Pathfinder Lander, Mercury Sample Return, Comet Surface Sample Return, Venus In Situ Explorer, and Europa Pathfinder Lander.

Sample handling technical challenges are driven by the goal of minimizing how much a sample is altered during handling. For example, if the temp of the sample handling system is higher than the sublimation temp of any volatile that you are interested in collecting, chances are you will lose some or all of it in the process of acquiring the sample. Contamination control is also critical; the intrinsic contamination level should ideally be lower than the measurement sensitivity of any analysis planned for a sample. Sample handling is an emerging technology required by near term Moon and Mars robotic missions as well as future colonization of the Moon. Revolutionary advances in sampling handling and control will be needed to meet the requirements of the table below.

| Sub Capability | Figures of Merit | Current Technology | Needed Technology |
|---|---|---|---|
| Sample Handling & Preparation | • Operability in relevant environment<br>• Degree of sample alteration<br>• Subsampling accuracy | • Bias from particle size and density<br>• Qualitative ability to preserve volatile fractions<br>• Operability over limited temperature ranges | • No bias or fractionation in end-to-end sample handling chain, even in multi-phase samples<br>• Ability to selectively subsample in primary sample acquisition<br>• Operability from 40K to 750K |
| Planetary Protection | • Sensitivity to detection of viable organisms<br>• Breadth of detection of viable organisms<br>• Degree of sterilization | • Characterization of viable organisms that can be cultured<br>• Detection levels well below sterilization levels | • Characterization of any viable organisms<br>• Sterilization levels on par with detection levels |

Basis of estimate are NASA technology programs for planetary science including the Planetary Instrument Definition and Development Program (PIDDP) and Mars Instrument Definition and Development Program (MIDDP), NASA's planetary missions, science community input and industry working groups.

## 12.7 Critical Facility Investments Summary

The table below was included in the Science Instruments and Sensors Technology Portfolio and refers to critical facilities investments needed to meet the major milestones listed in the Capability Cost Estimate Table.

| Capability | Critical Facility Need | Existing Facilities | Physical Infrastructure Planning |
|---|---|---|---|
| 12.1 Microwave Instruments and Sensors<br><br>12.2 Multi-Spectral Imaging / Spectroscopy (Vis-IR-FIR)<br><br>12.3 Multi-Spectral Sensing (UV-Gamma) | Stable and high-throughput fabrication infrastructure for large format detector arrays, readout multiplexers, and miniaturized instrument optics<br><br>High-throughput testing for large format detector arrays | NASA: GSFC (DDL), JPL (MDL) for detector arrays and miniaturized instrument optics;<br>NIST: Detector arrays and superconducting readout multiplexers<br>University: MIT Lincoln Labs, Caltech and UC Berkeley for detector arrays<br>Industry: Rockwell, Raytheon, and BAE for large format IR detector arrays and multiplexer readouts<br>NASA: GSFC (DCL), JPL, ARC<br>University: Princeton, Caltech, UC Berkeley, MIT, Univ. Hawaii<br>Industry: Vis-IR-UV | Critical for continued development of large format detector arrays. DOD community and commercial industry has little interest in FIR detectors. Sole source in NIST for superconducting readout multiplexers.<br>Detector fab and testing infrastructure requires substantial financial investment, which typical research awards cannot support<br>Many scientific detector arrays (microwave, FIR, IR, X-ray) operate at cryogenic temps, which requires a non–trivial cryogenic testing infrastructure. |
| 12.2 Multi-Spectral Imaging / Spectro-scopy (Vis-IR-FIR)<br>12.4 Laser / LIDAR Remote Sensing | Instrumented calibration regions<br><br>Aircraft and ground-based prototype testing | Rogers Dry Lake CA, Stennis Space Center MS, Cuprite NV, Barreal Blanco Argentina, Mt. Fitton and Lake Frome Australia, ocean sites near Hawaii and Bermuda | Critical for instrument calibration of the full field of the instrument over the full spectral range - especially for spectrometric imagers |

| Capability | Critical Facility Need | Existing Facilities | Physical Infrastructure Planning |
|---|---|---|---|
| 12.5 Direct Sensing of Fields, Particles and Waves | High charge state ion beam facility, keV energies; Neutral beam facility, 1 eV to 1 MeV; Solar corona simulator | U. Bern RF powered source, GSFC hollow cathode source.<br>U. Denver O/H facility currently inoperative owing to PI death | Establish NASA high charge state facility for community use<br><br>Establish NASA neutral atom source and beam facility for community use |
| 12.6 In Situ Instrumentation | Environmentally relevant instrument test beds to simulate conditions on Moon, Mars, Venus, etc. | Mars Yard at JPL; various non-dedicated thermal vacuum chambers | Environmentally relevant testbed will provide an important service to the community and reduce mission risk. |